PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04B 7/005, 7/01, 7/015, 15/00	A1	(11) International Publication Number: WO 99/22463 (43) International Publication Date: 6 May 1999 (06.05.99)

(21) International Application Number: PCT/US98/22801

(22) International Filing Date: 27 October 1998 (27.10.98)

(30) Priority Data:

08/959,409	28 October 1997 (28.10.97)	US
09/079,535	15 May 1998 (15.05.98)	US

(71) Applicant: MOTOROLA INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US).

(72) Inventors: GOLDBERG, Steven, Jeffrey; 4409 Foxfire Way, Fort Worth, TX 76133 (US). BUDNIK, Brian, Joseph; 6413 Old Mill Circle, Watauga, TX 76148 (US). SEXTON, Thomas, Aloysius; Apartment 224, 5333 Fossil Creek Boulevard, Fort Worth, TX 76137 (US). CARSELLO, Stephen, Rocco; 8204 Ranier Road, Fort Worth, TX 76137 (US).

(74) Agents: BETHARDS, Charles, W. et al.; Motorola Inc., Intellectual Property Dept., 5401 North Beach Street/MS E230, Fort Worth, TX 76137 (US).

(81) Designated States: CA, CN, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

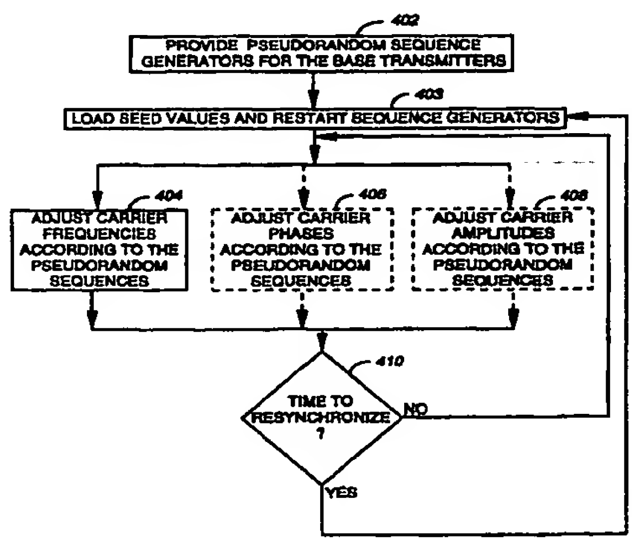
Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: LIMITING AN INTERVAL OF CARRIER CANCELLATION AND REDUCING ERRORS CAUSED BY INTERSYMBOL INTERFERENCE DURING A SIMULCAST TRANSMISSION

(57) Abstract

In a messaging system having a plurality of simulcasting base transmitters (104), a plurality of pseudorandom sequence generators (216) are provided (402) for the plurality of base transmitters. The plurality of pseudorandom sequence generators are arranged (403) to ensure that they generate a plurality of pseudorandom sequences having sub–sequences that are different from one another during concurrent transmissions by the plurality of base transmitters. A cancellation–affecting parameter of the plurality of base transmitters is adjusted (404, 406, 408) in accordance with the plurality of pseudorandom sequences during the simulcast transmission from the plurality of base transmitters to limit intervals of carrier cancellation. In addition, a controller (512) controls (1106) at least two transmitters (702) to transmit at least two simulcast signals (902, 904) during a time period. The at least two simulcast signals produce intersymbol interference at a receiver. At least one of the transmitters changes (1108) its output amplitude during a portion of the time period, thereby altering the intersymbol interference during the portion of the time period.



400

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

LIMITING AN INTERVAL OF CARRIER CANCELLATION AND REDUCING ERRORS CAUSED BY INTERSYMBOL INTERFERENCE DURING A SIMULCAST TRANSMISSION

Field of the Invention

This invention relates in general to radio communication systems, and more specifically to a method and apparatus in a messaging system for limiting an interval of carrier cancellation and for reducing errors caused by intersymbol interference during a simulcast transmission.

Background of the Invention

Radio messaging systems have utilized simulcast transmissions from multiple transmitters for providing radio coverage to large geographic areas. During a simulcast transmission a receiver positioned midway between two transmitters often can receive signals from both transmitters. The resultant instantaneous sum of the two signals depends upon their relative phase, and can be either larger or smaller than either signal alone. For example, if the two signals are substantially equal in amplitude and phase at the receiver, their resultant sum will be about twice the amplitude of either signal alone. If, however, the two signals are substantially equal in amplitude and 180 degrees out of phase, their resultant sum can be so small as to be undetectable by the receiver, due to destructive cancellation of the two signals.

Modern messaging systems utilize forward error correcting codes and bit interleaving to allow messages to be transmitted successfully in the presence of brief fades and noise bursts. Thus, an error-free message can be received even in the presence of intervals of destructive cancellation, provided that the intervals of destructive cancellation are sufficiently brief. To ensure that the intervals of destructive cancellation are sufficiently brief, the prior art messaging systems have employed a technique of permanently offsetting the carrier frequencies of adjacent transmitters with respect to one another by a small, fixed amount, e.g., 15 to 100 Hz.

A problem with the technique of permanently offsetting the carrier frequencies of adjacent transmitters is that it requires additional system

planning and effort in setting up the radio messaging system. Furthermore, the technique can cause difficulties when adding new transmitters to an existing system, because the frequency offsets of many of the existing transmitters may have to be readjusted. In addition, some specific frequency offsets between adjacent transmitters, e.g., 200 Hz, are known to cause a higher word error rate, and should be avoided.

Good simulcast transmission has always required some form of delay equalization or launch time synchronization to ensure that the transmissions from different transmitters begin at the same time. For low speed data, having the transmissions begin at the same time has usually been sufficient. For the high speed data which is becoming more prevalent today, having the transmissions begin at the same time is necessary, but not sufficient. The reason is that differential transmission delay introduced in the air links can become a significant fraction of the symbol period when the symbol rate is high. When differential transmission delay becomes a significant fraction of the symbol period, intersymbol interference can occur when two or more simulcast signals arrive at the receiver with similar amplitudes. Such intersymbol interference can cause a high error rate in the received signal.

Thus, what is needed is a method and apparatus for limiting the intervals of destructive cancellation during simulcast transmissions. The method and apparatus preferably will limit the intervals of destructive cancellation without utilizing the prior art technique of permanently offsetting the carrier frequencies of adjacent transmitters with respect to one another.

What is further needed is a method and apparatus that can reduce errors caused by intersymbol interference during a simulcast transmission when two or more simulcast signals are received at similar amplitudes with different transmission delays. The method and apparatus preferably will operate without requiring a custom tuning adjustment during installation and system setup.

Summary of the Invention

An aspect of the present invention is a method in a messaging system having a plurality of base transmitters, the method for limiting an interval of carrier cancellation at a reception point during a simulcast

transmission. The method comprises the step of providing a plurality of pseudorandom sequence generators for the plurality of base transmitters, the plurality of pseudorandom sequence generators arranged to ensure that they generate a plurality of pseudorandom sequences having sub-sequences that are different from one another during concurrent transmissions by the plurality of base transmitters. The method further comprises the step of adjusting a cancellation-affecting parameter of the plurality of base transmitters in accordance with the plurality of pseudorandom sequences during the simulcast transmission from the plurality of base transmitters.

Another aspect of the present invention is a base transmitter in a messaging system having a plurality of base transmitters, the base transmitter for limiting an interval of carrier cancellation at a reception point during a simulcast transmission. The base transmitter comprises a transmitter element for transmitting a message, and a processing system coupled to the transmitter element for controlling the transmitter element to transmit the message. The base transmitter further comprises an input interface coupled to the processing system for receiving the message; and a pseudorandom sequence generator coupled to the transmitter element, the pseudorandom sequence generator arranged to ensure that it generates a pseudorandom sequence having sub-sequences that are different from those generated in other ones of the plurality of base transmitters during concurrent transmissions by the plurality of base transmitters. The transmitter element is arranged such that the pseudorandom sequence generator adjusts a cancellation-affecting parameter of the transmitter element in accordance with the pseudorandom sequence during the simulcast transmission from the base transmitter.

A third aspect of the present invention is a method in a messaging system having a plurality of base transmitters, the method for limiting an interval of carrier cancellation at a reception point during a simulcast transmission. The method comprises the step of providing a plurality of pseudorandom sequence generators for the plurality of base transmitters, the plurality of pseudorandom sequence generators arranged to generate a plurality of pseudorandom sequences having sub-sequences that have more than a predetermined probability of being different from one another during concurrent transmissions by the plurality of base

transmitters. A parameter of the plurality of pseudorandom sequences is optimized according to a characteristic of a communication protocol utilized by the messaging system. The method further comprises the step of adjusting a cancellation-affecting parameter of the plurality of base transmitters in accordance with the plurality of pseudorandom sequences during the simulcast transmission from the plurality of base transmitters.

A fourth aspect of the present invention is a method in a wireless communication system for reducing errors caused by intersymbol interference in at least two simulcast signals transmitted during a time period. The at least two simulcast signals are received at similar amplitudes and have different transmission delays with respect to one another. The method comprises the steps of transmitting the at least two simulcast signals from a corresponding at least two transmitters, and changing an output amplitude of at least one of the at least two transmitters during a portion of the time period, thereby altering the intersymbol interference during the portion of the time period.

A fifth aspect of the present invention is a transmitter in a wireless communication system for reducing errors caused by intersymbol interference in at least two simulcast signals transmitted during a time period. The at least two simulcast signals are received by a receiver at similar amplitudes and have different transmission delays with respect to one another. The transmitter comprises a transmitter element for transmitting a first simulcast signal sent simultaneously with at least a second simulcast signal from another transmitter, and a modulator coupled to the transmitter element for changing an output amplitude of the transmitter during a portion of the time period, thereby altering the intersymbol interference at the receiver during the portion of the time period.

A sixth aspect of the present invention is a controller in a wireless communication system for reducing errors caused by intersymbol interference in at least two simulcast signals transmitted during a time period. The at least two simulcast signals are received at similar amplitudes and have different transmission delays with respect to one another. The controller comprises a network interface for receiving a message from a message originator, and a processing system coupled to the network interface for processing the message. The controller further comprises a base station interface coupled to the processing system for

controlling a transmitter to transmit one of the at least two simulcast signals. The processing system is programmed to control the transmitter to change an output amplitude of the transmitter during a portion of the time period, thereby altering the intersymbol interference during the portion of the time period.

Brief Description of the Drawings

FIG. 1 is an electrical block diagram of a messaging system in accordance with the present invention.

FIG. 2 is an electrical block diagram of an exemplary inplementation of a base transmitter in accordance with the present invention.

FIG. 3 is a diagram depicting amplitude and relative phase of two carriers offset in frequency in accordance with the present invention.

FIG. 4 is a flow chart depicting operation of the messaging system in accordance with the present invention.

FIG. 5 is an electrical block diagram of an exemplary wireless communication system in accordance with the present invention.

FIG. 6 is an electrical block diagram of an exemplary controller in accordance with the present invention.

FIG. 7 is an electrical block diagram of an exemplary base station in accordance with the present invention.

FIG. 8 is a timing diagram depicting intersymbol interference in a prior art wireless communication system.

FIG. 9 is a timing diagram depicting reduced intersymbol interference in the wireless communication system in accordance with the present invention.

FIG. 10 is an exemplary protocol diagram in accordance with the present invention.

FIG. 11 is a flow diagram depicting operation of the exemplary wireless communication system in accordance with the present invention.

Detailed Description of the Drawings

Referring to FIG. 1, an electrical block diagram of a messaging system in accordance with the present invention comprises a plurality of

subscriber units 102, which communicate by radio with a fixed portion of the radio system, comprising a plurality of base transmitters 104 and a plurality of controllers 110. The base transmitters 104 are coupled via communication links 106 to the plurality of controllers 110 for control by and communication with the plurality of controllers 110 utilizing well-known techniques. The controllers 110 are coupled to a home controller 120 via communication links 122, 124, and via a conventional communication network 108 for receiving selective call messages from the home controller 120. The home controller 120 and the controllers 110 preferably communicate by utilizing a well-known protocol, e.g., the Telocator Network Paging Protocol (TNPP), the Wireless Messaging transfer protocol (WMtp™), or the InterPaging Networking Protocol (IPNP). It will be appreciated that, alternatively, the home controller 120 and the controller 110 can be collocated. The home controller 120 is preferably coupled via telephone links 126 to a public switched telephone network 112 (PSTN) for receiving the messages from message originators utilizing, for example, a telephone 114 or a personal computer 116 to originate the messages. It will be appreciated that, alternatively, other types of communication networks, e.g., packet switched networks, local area networks, and the Internet can be utilized as well for transporting originated messages to the home controller 120. The hardware of the home controller 120 is preferably similar to the Wireless Messaging Gateway (WMG™) Administrator! paging terminal, while the hardware of the controllers 110 is preferably similar to that of the RF-Conductor!™ message distributor, both manufactured by Motorola, Inc. of Schaumburg, IL. The hardware of the base transmitters 104 is preferably similar to that of the Nucleus® and RF-Orchestra!® transmitters manufactured by Motorola, Inc. It will be appreciated that other similar hardware can be utilized as well for the home controller 120, the controllers 110, and the base transmitters 104. It will be further appreciated that the present invention can be applied to both one-way and two-way selective call messaging systems.

The protocol utilized for transmitting the messages between the base transmitters 104 and the subscriber units 102 is preferably similar to Motorola's well-known FLEX™ family of digital selective call signaling protocols. These protocols utilize well-known error detection and error correction techniques and are therefore tolerant to bit errors occurring during transmission,

provided that the bit errors are not too numerous in any one code word. It will be appreciated that other similar messaging protocols can be used as well.

Referring to FIG. 2, an electrical block diagram depicts an exemplary inplementation of the base transmitter 104 in accordance with the present invention. The base transmitter 104 comprises an antenna 204 for emitting a radio signal comprising a message. The base transmitter 104 further comprises a conventional transmitter element 208 coupled to the antenna 204 for transmitting the message, and a processing system 206 coupled to the transmitter element 208 for controlling the transmitter element 208 to transmit the message. The processing system is further coupled to a conventional pseudorandom sequence generator 216, which is also coupled to the transmitter element 208. The pseudorandom sequence generator 216 is arranged to ensure that it generates a pseudorandom sequence having sub-sequences that are different from those generated in other ones of the plurality of base transmitters during concurrent transmissions by the plurality of base transmitters, as described further below. Preferably, the pseudorandom sequence generator 216 is further arranged to provide a pseudorandom sequence identical to that of other base transmitters of the plurality of base transmitters, but initialized, concurrently with the other base transmitters, with a seed value different from that of the other base transmitters. It will be appreciated that, alternatively, the pseudorandom sequence generator 216 can be arranged to provide a pseudorandom sequence that is different from that of other base transmitters 104 of the plurality of base transmitters by, for example, enabling different feedback taps on the pseudorandom sequence generators 216 associated with different base transmitters 104. In addition, the pseudorandom sequence generator 216 preferably has at least a predetermined minimum number of stages, e.g., 20 stages. This preference facilitates allowing the base transmitters 104 to be concurrently initialized with different seed values 226 derived, for example, from the serial number of the base transmitters 104. It also will be appreciated that, alternatively, the pseudorandom sequence generator 216 can be incorporated into the processing system 206, where its functions can be performed in software.

The transmitter element 208 is arranged such that the pseudorandom sequence generator 216 adjusts a cancellation-affecting parameter of the transmitter element 208 in accordance with the

pseudorandom sequence during a simulcast transmission from the base transmitter 104. More specifically, the transmitter element 208 preferably includes a conventional frequency modulator (not shown) coupled to the pseudorandom sequence generator 216 such that the pseudorandom sequence generator 216 adjusts the carrier frequency of the base transmitter 104 in accordance with the pseudorandom sequence. In the simplest case, the pseudorandom sequence generator 216 cooperates with the transmitter element 208 to adjust the carrier frequency of the base transmitter 104 to one of two levels, e.g., ±50 Hz, about a predetermined nominal carrier frequency. It will be appreciated that, alternatively, the pseudorandom sequence generator 216 and the transmitter element 208 can be arranged to adjust the carrier frequency to one of N predetermined levels in accordance with the pseudorandom sequence, N being an integer greater than unity. It will be further appreciated that, alternatively, the transmitter element 208 can be arranged such that another cancellation-affecting parameter of the base transmitter 104, e.g., the carrier phase or the carrier amplitude, is adjusted in accordance with the pseudorandom sequence, through well-known techniques. It also will be appreciated that, alternatively, the transmitter element 208 can be arranged such that the pseudorandom sequence generator 216 adjusts at least two cancellation-affecting parameters selected from a group of cancellation-affecting parameters consisting of the carrier frequency, the carrier phase, and the carrier amplitude. In addition, it will be appreciated that the pseudorandom sequence may have to be filtered to prevent instantaneous shifts of the cancellation-affecting parameter(s).

Preferably, the pseudorandom sequence generator 216 is further arranged to optimize a parameter of the plurality of pseudorandom sequences according to a characteristic of the communication protocol utilized by the messaging system, such that the intervals of destructive cancellation will exist only long enough to potentially destroy, i.e., change the value of, less than a predetermined number of bits, e.g., two bits, of a given (interleaved) code word, which will fall within the error correction capability of the protocol. This essentially moves the bit errors around, distributing them randomly such that the forward error correction is very likely to correct all the errors caused by the intervals of destructive cancellation.

For example, consider the FLEX protocol, which uses (32,21) BCH code words interleaved such that there are 5 ms intervals between bits corresponding to the same code word. Each block of interleaved code words lasts 160 ms. Consider the case of no dithering and no frequency offsets and a 1 Hz frequency error between two adjacent FM transmitters. The interval of destructive cancellation may last on the order of 100 ms, which will destroy most code word bits (exceeding the forward error correction capability) in 1 or 2 interleaved blocks of the transmission, yet leaving another 4 or 5 interleaved blocks error free. In this condition little benefit is derived from the forward error correction. Now consider the use of pseudorandom frequency dithering in accordance with the present invention, e.g., ± 50 Hz about a nominal frequency, with the duration of each dither set to 7.5 ms, for example. An interval of destructive cancellation lasting 7.5 ms and repeating no more frequently than every 160 ms will destroy, on average, 3/4 bit from each code word. If a random phase difference between two signals generates an interval of destructive cancellation with a probability of 0.1 (as derived further below), then, on average, a destructive phase condition will occur 1.6 times per code word in each block, advantageously allowing a greatly increased benefit from forward error correction coding.

Again referring to FIG. 2, the processing system 206 is further coupled to a conventional clock 202 for generating a timing signal for the base transmitter 104. The accuracy of the timing signal preferably is sufficient to maintain synchronization of the pseudorandom sequence generator 216 within a small time tolerance, e.g., 100 microseconds, between resynchronizations of the pseudorandom sequence generator 216. It will be appreciated that, alternatively, the timing signal can be derived from a Global Positioning Satellite (GPS) receiver. The processing system 206 is also coupled to a conventional input interface 214 for receiving the message via the communication link 106.

The processing system 206 comprises a conventional processor 210 and a conventional memory 212. The memory 212 includes locations for storing messages 222 received through the input interface 214 and, preferably, a pseudorandom sequence seed value 226 derived, for example, from a serial number uniquely assigned by the factory to the base transmitter 104. The memory 212 also includes software elements

for message processing 224 and pseudorandom sequence synchronization 228 in accordance with the present invention.

Referring to FIG. 3, a diagram 300 depicting amplitude (represented by length) and relative phase (θ) of two carriers A1, A2 offset in frequency in accordance with the present invention and received by a receiver at a reception point between two of the base transmitters 104. Assume, for example, that the frequency of the carrier A2 is higher than that of the carrier A1. The result is that the phase of A2 is changing faster with time than that of A1. Periodically, the relative phase θ at the receiver is such that A2 enters the shaded area defined as the zone of destructive cancellation 302. The zone of destructive cancellation 302 preferably is defined, by way of example, to correspond to

$$0.9\pi < \theta < 1.1\pi.$$

As θ traverses 2π for each full revolution, one can conclude that for a fixed, nonzero frequency difference between A1 and A2 the probability that A2 is in the zone of destructive cancellation 302 at a randomly chosen instant of time is $P = 0.1$. For a pseudorandomly varied frequency difference between A1 and A2 in accordance with the present invention the probability that A2 is in the zone of destructive cancellation 302 at a randomly chosen instant of time is also $P = 0.1$.

The instantaneous power at the receiver is

$$P(t) = (A1+A2\cos(\theta))^2 + (A2\sin(\theta))^2.$$

If $A1 = A2 = 1$, the average power is 2.0. At 0.9π and 1.1π the instantaneous power is approximately 0.1. Thus, within the defined zone of destructive cancellation 302 the instantaneous power is approximately 13 dB or more below the average power. While there is no way to prevent the two carriers A1 and A2 from entering the zone of destructive cancellation 302, it is highly desirable to minimize their stay in the zone, as is advantageously accomplished in accordance with the present invention, as described further below. It will be appreciated that, alternatively, other exemplary ranges of θ can be utilized to define the zone of destructive cancellation 302.

FIG. 4 is a flow chart 400 depicting operation of the messaging system in accordance with the present invention. The flow chart 400 begins with providing 402 the pseudorandom sequence generators 216 for the base transmitters 104. After the messaging system is powered up, the processing systems 206 access the seed values 226 corresponding to each of the base transmitters 104. The processing systems 206 then load 403 the seed values 226 and simultaneously restart the pseudorandom sequence generators 216. The restarting of the pseudorandom sequence generators 216 is preferably synchronized by the communication protocol to recur, for example, at the top of each hour. Concurrently restarting the pseudorandom sequence generators 216 periodically in this manner with different seed values 226 advantageously allows identical-sequence pseudorandom sequence generators 216 to be utilized for the base stations, while ensuring that the pseudorandom sequences contain sub-sequences that are different from one another during concurrent transmissions by the base transmitters 104 (due to the sequences being offset from one another by the different seed values 226). It will be appreciated that, alternatively, the pseudorandom sequence generators 216 can comprise different-sequence pseudorandom sequence generators to ensure that the pseudorandom sequences generated thereby are different from one base transmitter 104 to the next.

Next, the processing systems 206 preferably begin adjusting the carrier frequencies 404 of the corresponding transmitter elements 208 according to the pseudorandom sequences. Alternatively, the processing systems 206 can adjust another cancellation-affecting parameter, such as the carrier phases 406 and/or the carrier amplitudes 408 in addition to, or in lieu of, adjusting the carrier frequencies. For the case of frequency or phase adjustment, the processing systems 206 preferably are programmed to ensure a uniformly distributed phase between 0 and 2π. The processing systems 206 also check 410 whether it is time to resynchronize the pseudorandom sequence generators 216. If so, the flow returns to step 403. If not, the flow returns to the appropriate ones of the adjusting steps 404, 406 and 408.

Simulations in accordance with the present invention have demonstrated that by continuously adjusting a cancellation-affecting parameter of the base stations in accordance with the present invention, the intervals of destructive carrier cancellation advantageously are

limited in length and are randomly dispersed throughout the interleaved transmission blocks of the communication protocol, thereby substantially reducing the word error rate. The simulations have further demonstrated that no other carrier frequency offsetting technique is needed to meet performance objectives. In addition, by randomizing the starting points of the pseudorandom sequences through the use of seed values derived from a random number source, which can include the base station serial numbers, no additional system planning effort is required for adjusting the base stations relative to one another to limit carrier cancellation.

FIG. 5 is an electrical block diagram of an exemplary wireless communication system in accordance with the present invention, comprising a fixed portion 502 including a controller 512 and a plurality of base stations 516, the wireless communication system also including a plurality of receivers 522. The base stations 516 preferably communicate with the receivers 522 utilizing conventional radio frequency (RF) signals for sending simulcast transmissions in accordance with the present invention, as will be explained further below. The base stations 516 are coupled by communication links 514 to the controller 512, which controls the base stations 516.

The hardware of the controller 512 is preferably a combination of the Wireless Messaging Gateway (WMG™) Administrator! paging terminal, and the RF-Conductor!™ message distributor manufactured by Motorola, Inc., and includes software modified in accordance with the present invention. The base stations 516 comprise a transmitter preferably similar to the RF-Orchestra! transmitter, modified in accordance with the present invention, and can include, in two-way wireless communication systems, the RF-Audience!™ receiver manufactured by Motorola, Inc. The receivers 522 are preferably similar to the Advisor Gold™ and Pagefinder™ wireless communication units, also manufactured by Motorola, Inc. It will be appreciated that other similar hardware can be utilized as well for the controller 512, the base stations 516, and the receivers 522.

Each of the base stations 516 transmits RF signals to the receivers 522 via an antenna 518. The RF signals transmitted by the base stations 516 to the receivers 522 (outbound messages) comprise selective call addresses identifying the receivers 522, and voice and data messages originated by a caller, as well as commands originated by the controller 512 for adjusting operating parameters of the radio communication system.

The controller 512 preferably is coupled by telephone links 501 to a public switched telephone network (PSTN) 510 for receiving selective call message originations therefrom. Selective call originations comprising voice and data messages from the PSTN 510 can be generated, for example, from a conventional telephone 511 or a conventional computer 517 coupled to the PSTN 510. It will be appreciated that, alternatively, other types of communication networks, e.g., packet switched networks, the Internet, and local area networks, can be utilized as well for transporting originated messages to the controller 512.

The over-the-air protocol utilized for the transmissions is preferably selected from Motorola's well-known FLEX™ family of digital selective call signaling protocols. These protocols utilize well-known error detection and error correction techniques and are therefore tolerant to bit errors occurring during transmission, provided that the bit errors are not too numerous. It will be appreciated that other suitable protocols can be used as well. It will be further appreciated that, while one embodiment for practicing the present invention is a one-way wireless communication system, the present invention is applicable also to a two-way wireless communication system.

FIG. 6 is an electrical block diagram depicting an exemplary controller 512 in accordance with the present invention. The controller 512 comprises a network interface 618 for receiving a message from a message originator via the telephone links 501. The network interface 618 is coupled to a processing system 610 for controlling and communicating with the network interface 618. The processing system is coupled to a base station interface 604 for controlling and communicating with the base stations 516 via the communication links 514. The processing system 610 is also coupled to a conventional clock 630 for providing a timing signal to the processing system 610. The processing system 610 comprises a conventional computer 612 and a conventional mass medium 614, e.g., a magnetic disk drive, programmed with information and operating software in accordance with the present invention. The mass medium 614 comprises a subscriber database 620, including information about the receivers 522 controlled by the controller 512. The mass medium 614 also includes a message processing element 622 for programming the processing system 610 to process messages for the receivers 522 in a conventional manner. In accordance with the present invention, the mass medium 614 also includes a transmitter

output amplitude control element 624 for programming the processing system to control the transmitter 702 (FIG. 7) of the base stations 516 to change an output amplitude of the transmitter 702 during a portion of a time period during which simulcast transmissions are sent, thereby altering the intersymbol interference during the portion of the time period.

FIG. 7 is an electrical block diagram of an exemplary base station 516 in accordance with the present invention. The base station 516 comprises the antenna 518 for radiating a signal comprising a message. The antenna 518 is coupled to a transmitter 702 for transmitting the message. The transmitter 702 preferably comprises a conventional frequency shift keyed (FSK) transmitter element 708 for transmitting a first simulcast signal sent simultaneously with at least a second simulcast signal from another transmitter 702 (as coordinated by the controller 512 through well-known techniques). It will be appreciated that, alternatively, other types of transmitter elements for demodulating other types of modulated signals can be utilized as well for the transmitter element 708. The transmitter 702 further comprises a conventional amplitude modulator 703 coupled to the transmitter element 708 for changing an output amplitude of the transmitter 702 during a portion of the time period of the first simulcast signal, thereby altering the intersymbol interference at the receiver during the portion of the time period. The transmitter 702 is coupled to a processing system 706 for processing the message and for controlling the transmitter 702 in accordance with the present invention. A conventional controller interface 714 preferably is also coupled to the processing system 706 for interfacing with the controller 512 via the communication link 514 through well-known techniques. In addition, a conventional clock 707 is coupled to the processing system 706 for providing a timing signal thereto.

The processing system 706 comprises a conventional processor 710 and a conventional memory 712. The memory 712 comprises software elements and other variables for programming the processing system 706 in accordance with the present invention. The memory 712 includes a transmitter control element 722 for controlling the transmitter 702 through well-known techniques. In addition, the memory 712 includes a message processing element 724 for programming the processing system 706 to process the message in a conventional manner. The memory 712

further comprises a transmitter output amplitude control element 726 for cooperating with the modulator 703 to control the output amplitude of the transmitter 702 in accordance with the present invention, as described further below.

FIG. 8 is an exemplary timing diagram 800 depicting intersymbol interference in a prior art wireless communication system. The diagram 800 depicts amplitude versus time of a first signal 802 from a first simulcast transmitter and a second signal 804 from a second simulcast transmitter, the second signal 804 identical to, but delayed with respect to, the first signal 802. When the first and second signals 802, 804 are received by a receiver at nearly the same amplitudes, e.g., less than 4 dB of difference, the received signal 806 can comprise indeterminant areas 808 where the received bit cannot be decoded. When the indeterminant areas 808 occupy more than about 50% of the symbol period (corresponding to a differential delay of 25% of the symbol period), receiver sensitivity begins to be reduced slightly. When the indeterminant areas increase to 100% of the symbol period (corresponding to a differential delay of 50% of the symbol period), receiver sensitivity is reduced to zero.

FIG. 9 is an exemplary timing diagram 900 depicting reduced intersymbol interference in the wireless communication system in accordance with the present invention. The diagram 900 depicts amplitude versus time of a first signal 902 and a second signal 904. A "nominal" value of the amplitude of the first and second signals is represented by the dashed lines 910. Note that during a portion of the time period of the first and second signals 902, 904, the amplitude is changed above and/or below the nominal value, preferably by adjusting the output amplitude of the transmitter 702 by the modulator 703 under control of the processing system 706, in accordance with the present invention. When the nominal values of the first and second signals 902, 904 would be received by a receiver at nearly the same amplitudes, the advantageous effect of changing the output amplitudes of the first and second signals 904, 904 is demonstrated by the decoded signal 906. Note that the indeterminant areas 908 advantageously are reduced in number compared to the diagram 800. The reason for the reduced number of indeterminant areas 908 is that when the amplitudes of the first and second signals 902, 904 are different by more than about 4 dB, receiver

"capture" causes one of the signals to dominate, and the intersymbol interference goes away.

FIG. 10 is an exemplary protocol diagram 1000 in accordance with the present invention. This protocol is used by the controller 912 to communicate to the base station 916 how the transmitter 702 is to change its output amplitude during simulcast transmissions. The diagram 1000 comprises a synchronization portion 1002 for synchronizing the base station 916 with the communications of the controller 912, using well-known techniques. The diagram 1000 further comprises a type indication 1004 for indicating the message type, e.g., output amplitude control command. In addition, the diagram 1000 includes a command 1006 for controlling the output amplitude configuration of the base station transmitter 702. This protocol advantageously allows the base station 916 to be reconfigured from time to time with regard to how it changes the output amplitude of its transmissions in accordance with the present invention. As an alternative, the base station 916 can be pre-programmed, either in the field or during manufacture, with fixed instructions as to how the transmitter 702 should change its output amplitude during simulcast transmissions.

FIG. 11 is a flow diagram 1100 depicting operation of the exemplary wireless communication system in accordance with the present invention. The diagram 1100 preferably begins with the controller 912 communicating with the base station 916 to control 1102 the transmitter 1102 to change the output amplitude of its transmissions during a portion of the time period of each simulcast transmission. Simulations have shown that relatively small changes in the output amplitude, e.g. about ±0.5 dB, can produce a sizable, e.g., two to one, improvement in word error rate. Alternatively, the transmitter 1102 can be arranged 1104 during installation and setup, or during manufacture, to change the output amplitude during a portion of the time period of each simulcast transmission. However the transmitter 1102 is programmed, the controller 912 then controls the base stations 916 to send a simulcast transmission. The transmitter 1102 then performs 1106 according to its programmed instructions for changing the output amplitude. Preferably, the transmitter 1102 changes the output amplitude as a predetermined function of time, in synchronism with the symbols transmitted by the transmitter 1102.

In one embodiment, the transmitter 1102 is arranged such that the output amplitude of a central portion of each symbol does not change, while the output amplitude of non-central portions of the symbol do change. This technique exploits the fact that with normally encountered differential delay characteristics, intersymbol interference occurs primarily in the non-central portions of the symbols. In another embodiment, the transmitted signal comprises an error correcting code that can correct a predetermined number of errors in a code block, and the transmitter 1102 changes the output amplitude according to a pseudorandom sequence having a predetermined number of states, e.g., two states, during a transmission of the code block. In this embodiment, it is preferred that the transmitters 1102 in the wireless communication system utilize pseudorandom sequences that are offset from one another, so that different transmitters 1102 do not adjust their output amplitudes identically at every step of the sequence. In yet another embodiment, the transmitter 1102 is arranged to repeat a change to the output amplitude for a number of symbols, wherein the number of symbols is determined from an encoding characteristic employed by the wireless communication system, e.g., the length of an error correcting code block.

Regardless which embodiment in accordance with the present invention is used, an overall objective is to reduce errors due to intersymbol interference. When used with an error correcting code, the present invention often can reduce the number of received errors sufficiently to change an uncorrectable number of errors into a correctable number of errors, thereby advantageously salvaging a message which would otherwise have been corrupted.

Thus, it should be clear from the preceding disclosure that the present invention provides a method and apparatus for limiting the intervals of destructive cancellation during simulcast transmissions. The method and apparatus advantageously limits the intervals of destructive cancellation without utilizing the administratively difficult prior art technique of permanently offsetting the carrier frequencies of adjacent transmitters with respect to one another. In addition, the present invention provides a method and apparatus that advantageously reduces errors caused by intersymbol interference during a simulcast transmission when two or more simulcast signals are received at similar amplitudes with different transmission delays. The method and

apparatus operates without requiring a custom tuning adjustment during installation and system setup.

Many modifications and variations of the present invention are possible in light of the above teachings. Thus, it is to be understood that, within the scope of the appended claims, the invention can be practiced other than as described herein above for the exemplary embodiments.

What is claimed is:

CLAIMS

1. A method in a messaging system having a plurality of base transmitters, the method for limiting an interval of carrier cancellation at a reception point during a simulcast transmission, the method comprising the steps of:

providing a plurality of pseudorandom sequence generators for the plurality of base transmitters, the plurality of pseudorandom sequence generators arranged to ensure that they generate a plurality of pseudorandom sequences having sub-sequences that are different from one another during concurrent transmissions by the plurality of base transmitters; and

adjusting a cancellation-affecting parameter of the plurality of base transmitters in accordance with the plurality of pseudorandom sequences during the simulcast transmission from the plurality of base transmitters.

2. A base transmitter in a messaging system having a plurality of base transmitters, the base transmitter for limiting an interval of carrier cancellation at a reception point during a simulcast transmission, the base transmitter comprising:

a transmitter element for transmitting a message;

a processing system coupled to the transmitter element for controlling the transmitter element to transmit the message;

an input interface coupled to the processing system for receiving the message; and

a pseudorandom sequence generator coupled to the transmitter element, the pseudorandom sequence generator arranged to ensure that it generates a pseudorandom sequence having sub-sequences that are different from those generated in other ones of the plurality of base transmitters during concurrent transmissions by the plurality of base transmitters,

wherein the transmitter element is arranged such that the pseudorandom sequence generator adjusts a cancellation-affecting parameter of the transmitter element in accordance with the pseudorandom sequence during the simulcast transmission from the base transmitter.

3. The base transmitter of claim 2, wherein the transmitter element is further arranged such that the pseudorandom sequence generator adjusts a carrier frequency of the base transmitter.

4. The base transmitter of claim 2, wherein the transmitter element is further arranged such that the pseudorandom sequence generator adjusts a carrier phase of the base transmitter.

5. The base transmitter of claim 2, wherein the transmitter element is further arranged such that the pseudorandom sequence generator adjusts a carrier amplitude of the base transmitter.

6. The base transmitter of claim 2, wherein the transmitter element is further arranged such that the pseudorandom sequence generator adjusts at least two cancellation-affecting parameters selected from a group of cancellation-affecting parameters consisting of a carrier frequency, a carrier phase, and a carrier amplitude.

7. The base transmitter of claim 2, wherein the pseudorandom sequence generator is further arranged to optimize a parameter of the plurality of pseudorandom sequences according to a characteristic of a communication protocol utilized by the messaging system.

8. The base transmitter of claim 2, wherein the pseudorandom sequence generator is further arranged to provide a pseudorandom sequence identical to that of other base transmitters of the plurality of base transmitters but initialized, concurrently with the other base transmitters, with a seed value different from that of the other base transmitters.

9. The base transmitter of claim 2, wherein the pseudorandom sequence generator is further arranged to provide a pseudorandom sequence that is different from that of other base transmitters of the plurality of base transmitters.

10. The base transmitter of claim 2, wherein the pseudorandom sequence generator has at least a predetermined minimum number of stages.

11. The base transmitter of claim 2,

wherein the transmitter element is further arranged to adjust the cancellation-affecting parameter to one of N predetermined levels in accordance with the pseudorandom sequence, N being an integer greater than unity.

12. A method in a messaging system having a plurality of base transmitters, the method for limiting an interval of carrier cancellation at a reception point during a simulcast transmission, the method comprising the steps of:

providing a plurality of pseudorandom sequence generators for the plurality of base transmitters, the plurality of pseudorandom sequence generators arranged to generate a plurality of pseudorandom sequences having sub-sequences that have more than a predetermined probability of being different from one another during concurrent transmissions by the plurality of base transmitters, wherein a parameter of the plurality of pseudorandom sequences is optimized according to a characteristic of a communication protocol utilized by the messaging system; and

adjusting a cancellation-affecting parameter of the plurality of base transmitters in accordance with the plurality of pseudorandom sequences during the simulcast transmission from the plurality of base transmitters.

13. A method in a wireless communication system for reducing errors caused by intersymbol interference in at least two simulcast signals transmitted during a time period, the at least two simulcast signals received at similar amplitudes and having different transmission delays with respect to one another, the method comprising the steps of:

transmitting the at least two simulcast signals from a corresponding at least two transmitters; and

changing an output amplitude of at least one of the at least two transmitters during a portion of the time period, thereby altering the intersymbol interference during the portion of the time period.

14. A transmitter in a wireless communication system for reducing errors caused by intersymbol interference in at least two simulcast signals transmitted during a time period, the at least two simulcast signals received by a receiver at similar amplitudes and having different transmission delays with respect to one another, the transmitter comprising:

a transmitter element for transmitting a first simulcast signal sent simultaneously with at least a second simulcast signal from another transmitter; and

a modulator coupled to the transmitter element for changing an output amplitude of the transmitter during a portion of the time period, thereby altering the intersymbol interference at the receiver during the portion of the time period.

15. The transmitter of claim 14, wherein the modulator is arranged to change the output amplitude in synchronism with a symbol transmitted from the transmitter.

16. The transmitter of claim 14, wherein the modulator is arranged to change the output amplitude as a predetermined function of time.

17. The transmitter of claim 14,

wherein the modulator is arranged to change the output amplitude in synchronism with a symbol transmitted from the transmitter, such that the output amplitude of a central portion of the symbol does not change, while the output amplitude of non-central portions of the symbol do change.

18. The transmitter of claim 14,

wherein the first simulcast signal comprises an error correcting code that can correct a predetermined number of errors in a code block, and

wherein the modulator is arranged to change the output amplitude according to a pseudorandom sequence having a predetermined number of states during a transmission of the code block.

19. The transmitter of claim 14, wherein the modulator is arranged to repeat a change to the output amplitude for a number of symbols, wherein the number of symbols is determined from an encoding characteristic employed by the wireless communication system.

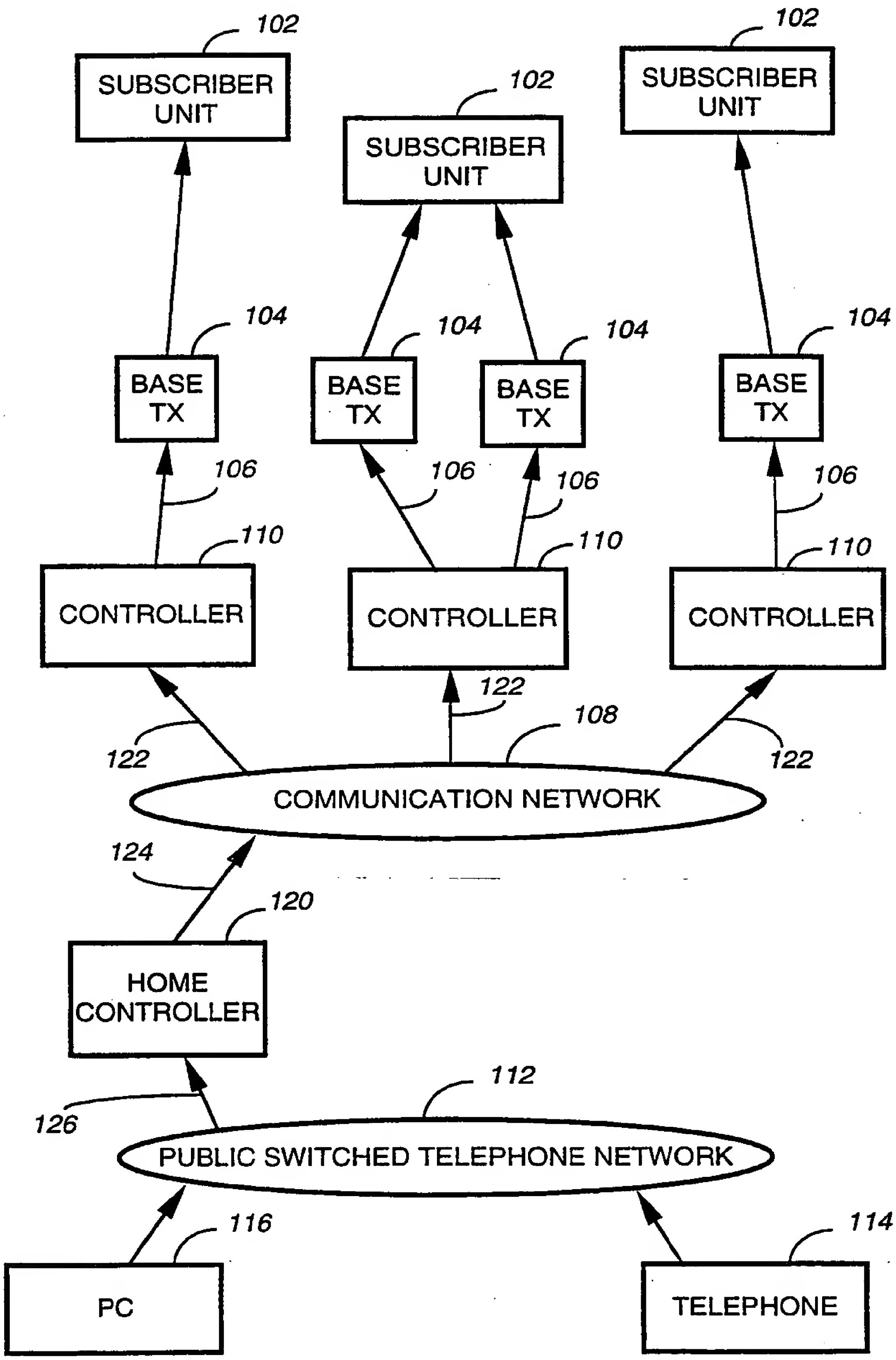
20. A controller in a wireless communication system for reducing errors caused by intersymbol interference in at least two simulcast signals transmitted during a time period, the at least two simulcast signals received at similar amplitudes and having different transmission delays with respect to one another, the controller comprising:

a network interface for receiving a message from a message originator;

a processing system coupled to the network interface for processing the message; and

a base station interface coupled to the processing system for controlling a transmitter to transmit one of the at least two simulcast signals,

wherein the processing system is programmed to control the transmitter to change an output amplitude of the transmitter during a portion of the time period, thereby altering the intersymbol interference during the portion of the time period.



102
SUBSCRIBER UNIT
102
SUBSCRIBER UNIT
102
SUBSCRIBER UNIT
104
BASE TX
104
BASE TX
104
BASE TX
104
BASE TX
106
106
106
106
110
CONTROLLER
110
CONTROLLER
110
CONTROLLER
122
122
108
122
COMMUNICATION NETWORK
124
120
HOME CONTROLLER
112
126
PUBLIC SWITCHED TELEPHONE NETWORK
116
114
PC
TELEPHONE

FIG. 1

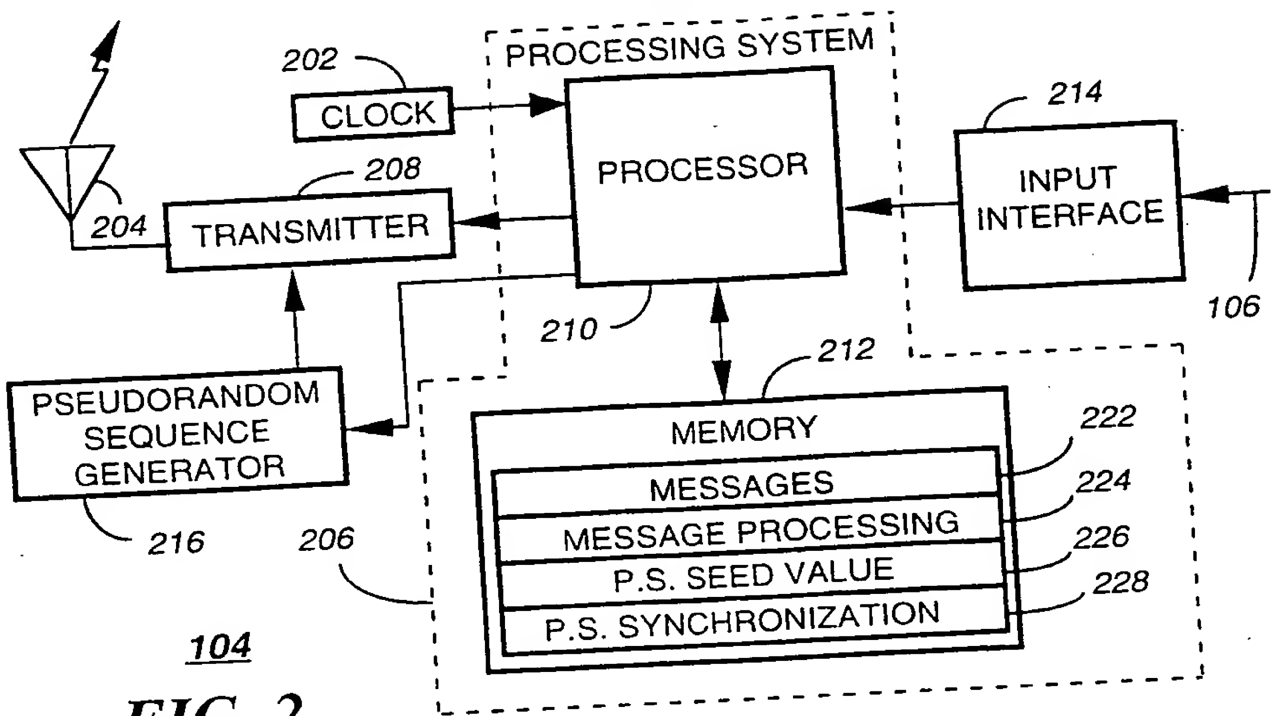

202
CLOCK
PROCESSING SYSTEM
PROCESSOR
214
INPUT INTERFACE
208
TRANSMITTER
204
210
106
212
MEMORY
222
MESSAGES
224
MESSAGE PROCESSING
226
P.S. SEED VALUE
228
P.S. SYNCHRONIZATION
PSEUDORANDOM SEQUENCE GENERATOR
216
206
104

FIG. 2

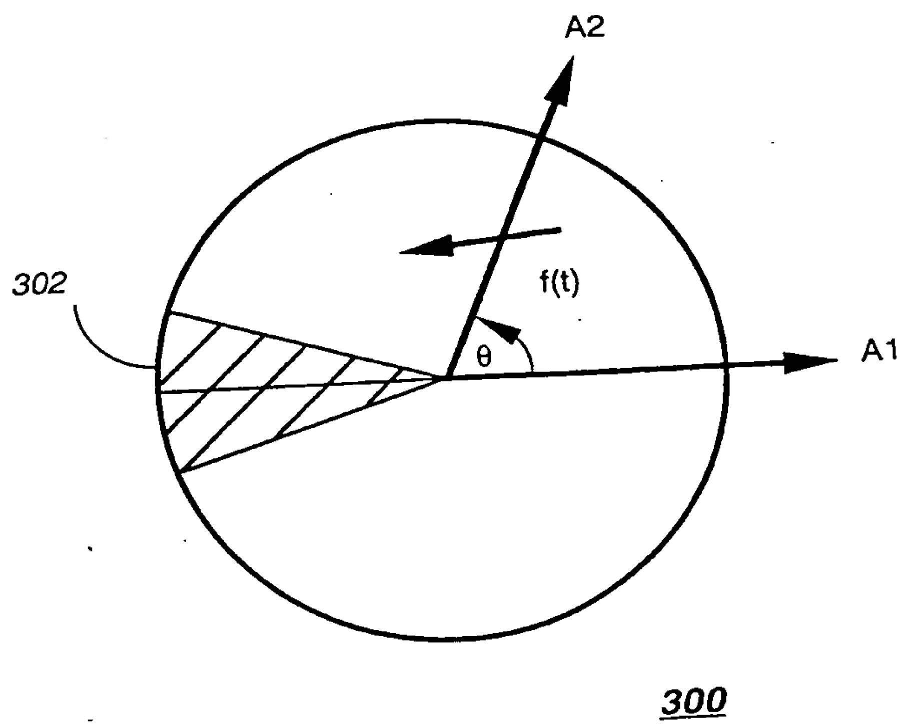
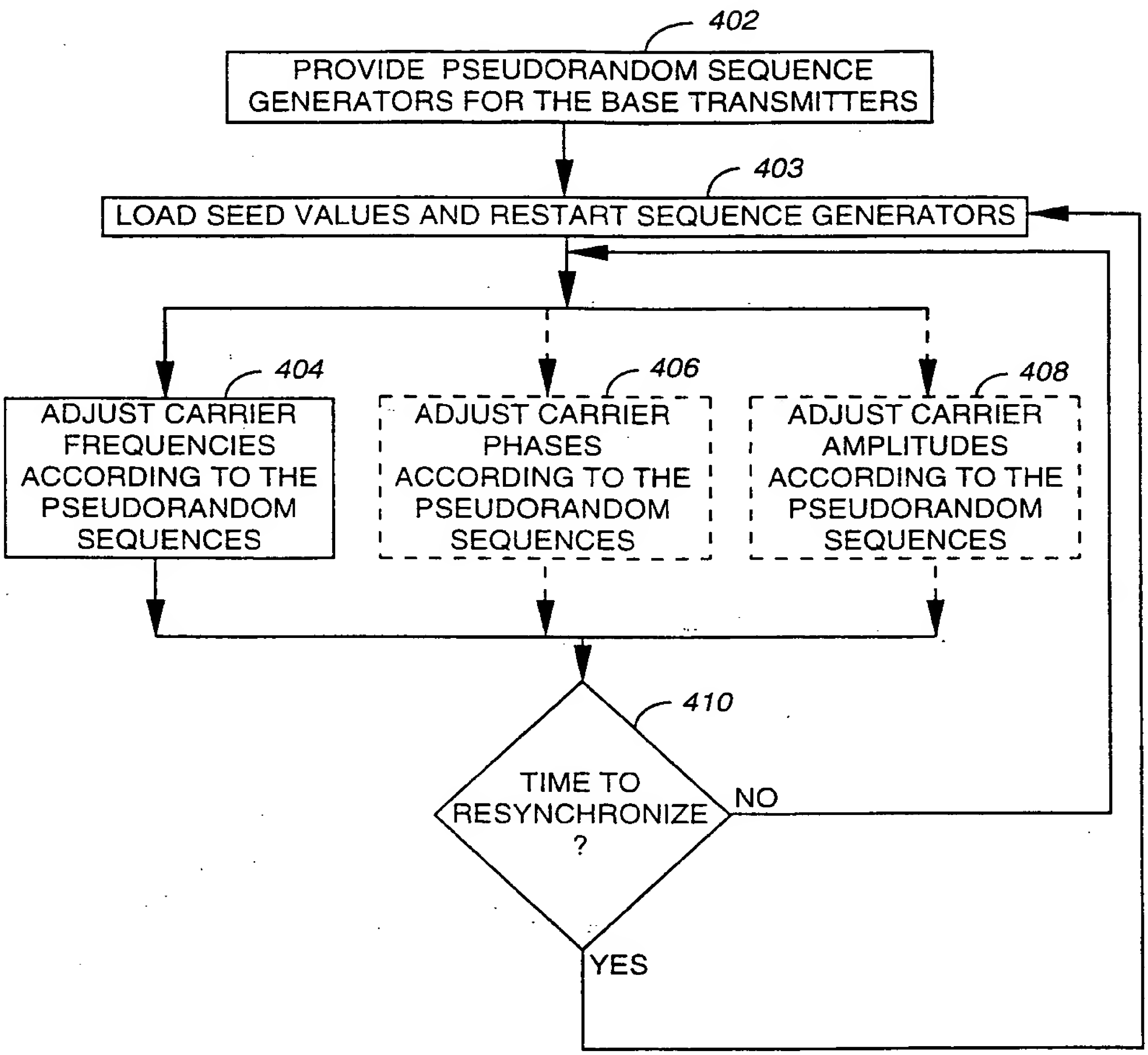

A2
302
f(t)
θ
A1
300

FIG. 3


402
PROVIDE PSEUDORANDOM SEQUENCE GENERATORS FOR THE BASE TRANSMITTERS
403
LOAD SEED VALUES AND RESTART SEQUENCE GENERATORS
404
ADJUST CARRIER FREQUENCIES ACCORDING TO THE PSEUDORANDOM SEQUENCES
406
ADJUST CARRIER PHASES ACCORDING TO THE PSEUDORANDOM SEQUENCES
408
ADJUST CARRIER AMPLITUDES ACCORDING TO THE PSEUDORANDOM SEQUENCES
410
TIME TO RESYNCHRONIZE ?
NO
YES

400

FIG. 4

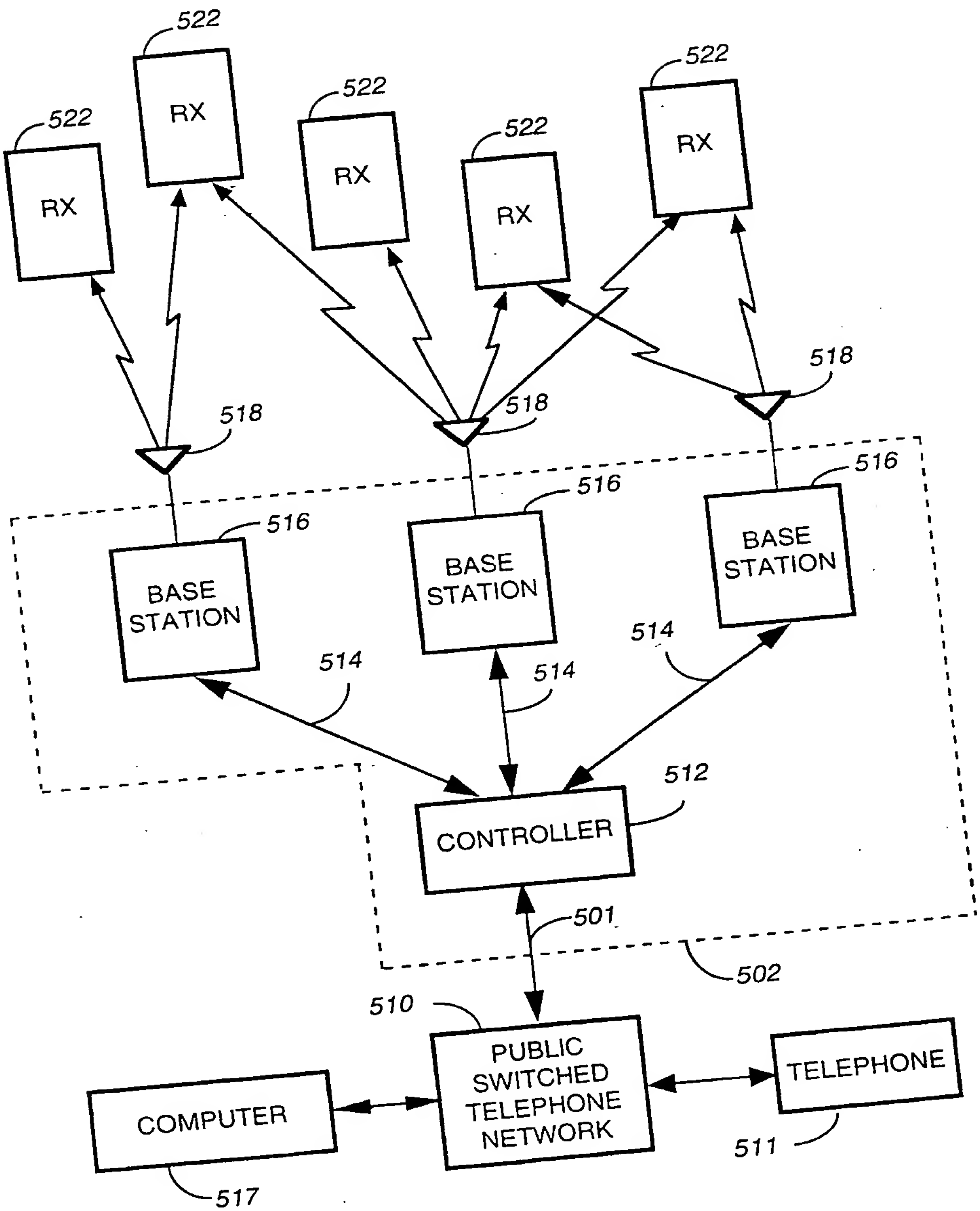
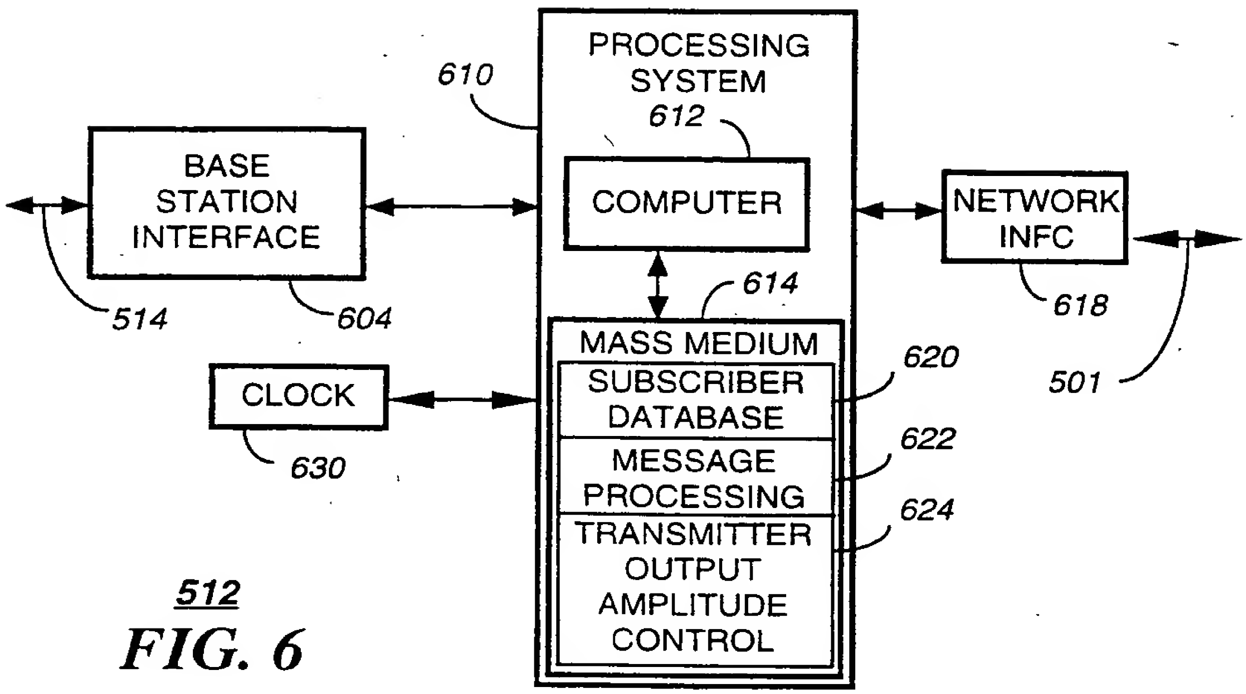
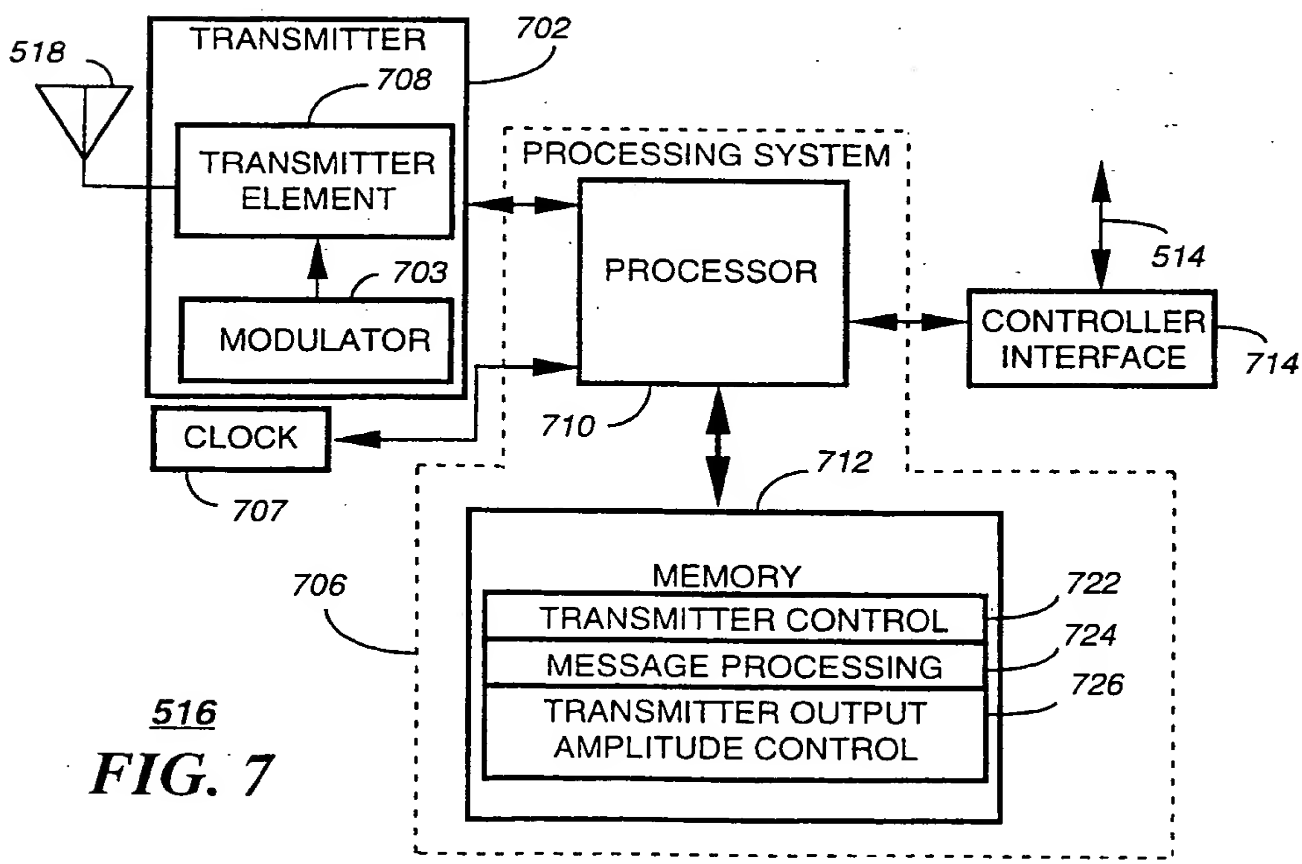

522
RX
522
RX
522
RX
522
RX
522
RX
518
518
518
516
516
516
BASE STATION
BASE STATION
BASE STATION
514
514
514
512
CONTROLLER
501
502
510
PUBLIC SWITCHED TELEPHONE NETWORK
COMPUTER
TELEPHONE
511
517

FIG. 5



512
FIG. 6



516
FIG. 7

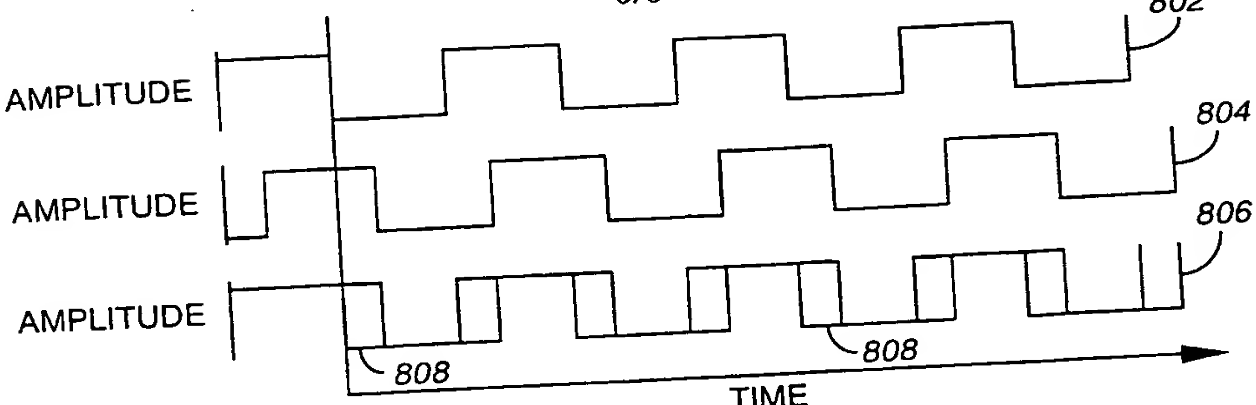
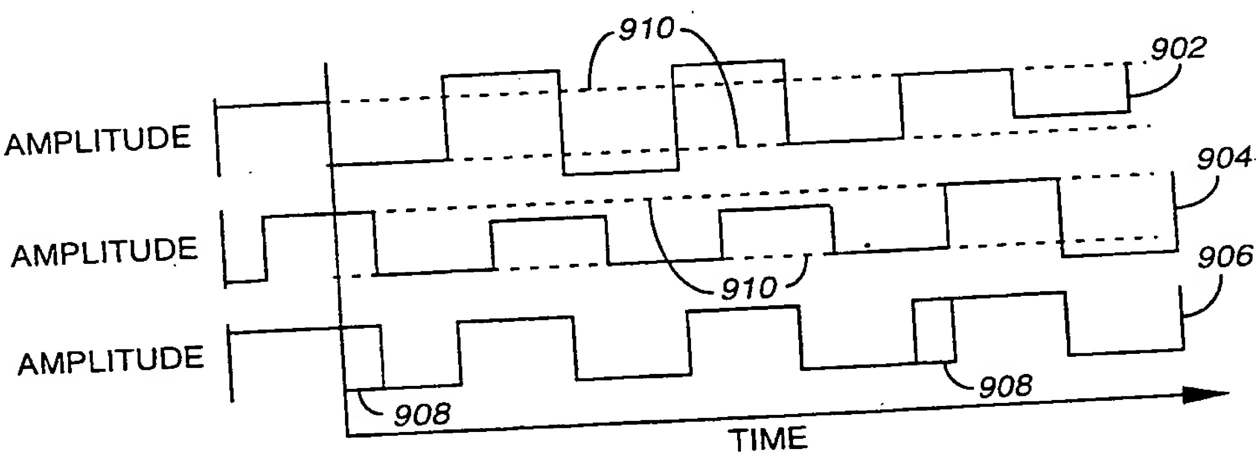


FIG. 8 800 PRIOR ART



900 FIG. 9

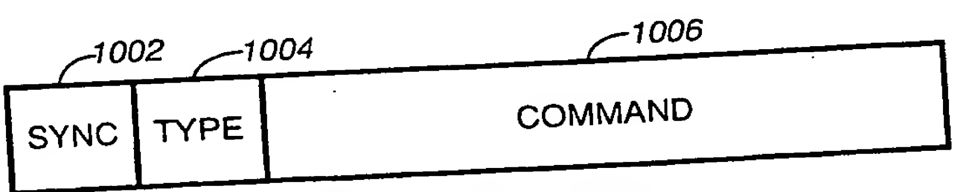


FIG. 10 1000

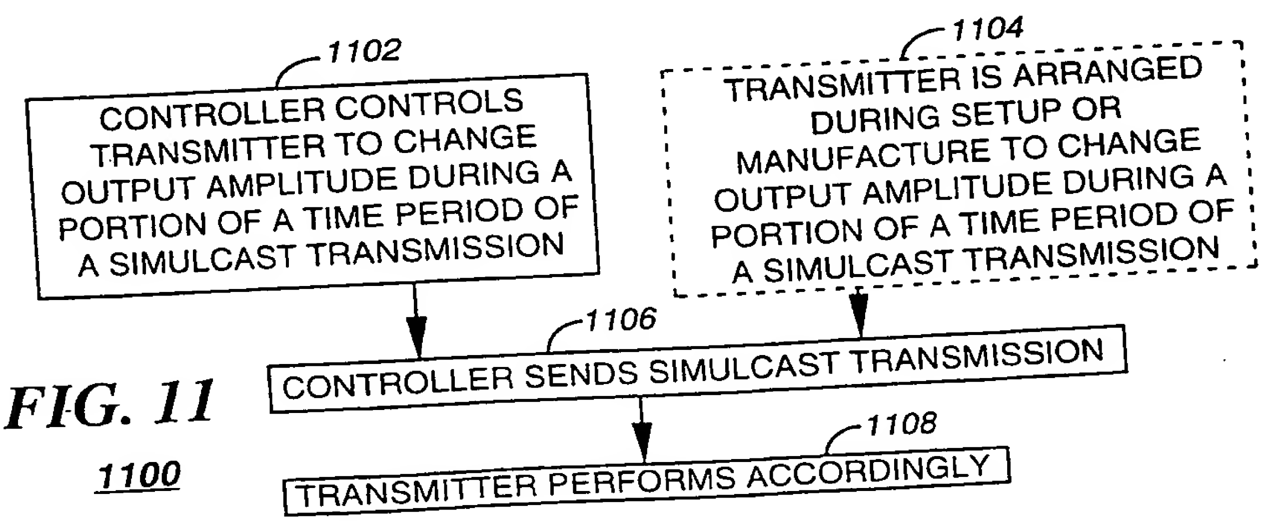


FIG. 11 1100

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/22801

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO4B 7/005, 7/01, 7/015, 15/00
US CL : 455/503
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/503, 31.1, 31.2, 38.1, 59, 67.6; 340/825.44

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,392,452 A (DAVIS) 21 FEBRUARY 1995, see abstract	1-20
A,P	US 5,802,117 A (GHOSH) 01 SEPTEMBER 1998, see column 4, line 35 through column 9, line 12	1-20
A	US 5,353,307 A (LESTER et al.) 04 OCOTOBER 1994, see abstract.	1-20
A,P	US 5,737,322 A (BURBIDGE et aL.) 07 APRIL 7, 1998, see all	1-20
A	US 5,535,215 A (HIEATT, III) 09 JULY 1996, see figure 2	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 DECEMBER 1998	25 FEB 1999

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	DARNELL R. ARMSTRONG
Facsimile No. (703) 305-3230	Telephone No. (703) 306-3015

Hill

Form PCT/ISA/210 (second sheet)(July 1992)★